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BREEDING PATTERNS IN SOUTHERN KOREAN CARABINA (COLEOPTERA, CARABIDAE)

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Abstract.—Breeding patterns of the subtribe Carabina were investigated on Mt. Sobaek and Mt. P'algong in Korea. Two different breeding patterns were distinguished by the developmental conditions of the female gonads: *Carabus sternbergi, Lipaster venustus, Eurycarabus fraterculus* and *Damaster leechi* were spring breeding types, and *Leptocarabus koreanus, L. semiopacus, L. seishinensis, Damaster jankowskii* and *D. smaragdinus* were autumn breeding types.

Key Words: Breeding patterns, Carabina

Annual breeding types of carabid beetles have frequently been classified into two major groups according to their reproductive season (spring or autumn) and hibernation stage (adults or larvae) in the temperate zone (Lindroth 1949, Thiele 1977, Paarmann 1979): Spring breeders hibernate as adults and reproduce from spring to early summer, and autumn breeders reproduce in autumn or even from midsummer and hibernate as larvae.

Sota (1985) concluded that the life history patterns of the ten species of the subtribe Carabina in Japan, eight species were categorized as spring breeders without larval hibernation and two species were autumn breeders with larval hibernation.

In the fauna of Korean Carabina, many geographical variations in the subspecific levels were reported (Ishikawa and Kim 1983, Kwon and Lee 1984). However, they were restricted to morphological viewpoints and for the further comprehension of their adaptive strategies and species diversification, detailed surveys of carabid life cycles are therefore needed.

In the present paper, for providing information on the future studies of the Korean carabid species, the authors investigated the breeding patterns of the Carabina on Mt. Sobaek and Mt. P'algong, both located in southern Korea.

MATERIALS AND METHODS

Areas surveyed

This study was conducted on Mt. Sobaek (1439 m, 37°57′N, 128°29′E) and Mt. P'algong (1192 m, 36°1′N, 128°42′E) in southern Korea. On Mt. Sobaek, from April to October in 1989, five sampling sites were chosen in deciduous forests at the following altitudes: ca. 600 m, 800 m, 1000 m, 1200 m and 1400 m above sea level. On Mt. P'algong, from August to October in 1989 and from April to July in 1990, three sampling sites were chosen in deciduous forests at the following altitudes: ca. 400 m, 600 m, and 800 m above sea level.

Methods

The materials were collected by pitfall traps at fortnightly intervals and the traps were exposed for two days. The trap was a

Table 1. Carabids collected and investigated from Mt. Sobaek (1989) and Mt. P'algong (1989–1990).

Mt. Sobaek	Mt. P'algong
Carabus (*Eucarabus*) *sternbergi* Roe. (=*C.* (*Parhomopterus*) *sternbergi sobaeksanensis* K. et L.)	*Carabus* (*Eucarabus*) *sternbergi* Roe. (=*C.* (*Parhomopterus*) *sternbergi palgongsanensis* K. et L.)
Lipaster (*Morphocarabus*) *venustus taebeagsanus* Ishi.	*Leptocarabus* (*Weolseocarabus*) *koreanus coreanicus* (Breu.)
Leptocarabus (*Weolseocarabus*) *koreanus* Roe. (=*L.* (*W.*) *koreanus minor* K. et L.)	*Leptocarabus* (*Adelocarabus*) *semipacus* (Reitter)
Leptocarabus (*Adelocarabus*) *semiopacus* (Reitter)	*Leptocarabus* (*Adelocarabus*) *seishinensis seishinensis* Lap.
Leptocarabus (*Adelocarabus*) *seishinensis seishinensis* Lap.	*Eurycarabus* (*Tomocarabus*) *fraterculus assimilis* K. et L.
Eurycarabus (*Tomocarabus*) *fraterculus assimilis* K. et L.	*Damaster* (*Coptolabrus*) *jankowskii jankowskii* (Ober.)
Damaster (*Acoptolabrus*) *leechi* (Bat.)	*Damaster* (*Coptolabrus*) *smaragdinus branickii* (Tac.)
Damaster (*Coptolabrus*) *jankowskii jankowskii* (Ober.)	
Damaster (*Coptolabrus*) *smaragdinus fulminifer* (Roe.)	

plastic cup of 6.5 cm in top diameter and 7.2 cm in height. Fifty traps were buried at about 3 m intervals at each site. They were classified according to the degree of gonadal development of the females into three categories: 1) New or virgin female, without mature eggs and corpora lutea; 2) Reproductive female, with mature eggs; 3) Spent or post reproductive female, without mature eggs but with corpora lutea. Those of two or more years as adults were distinguished from new adults during the non-reproductive period by the presence of corpora lutea.

Results

On Mt. Sobaek nine species under five genera and on Mt. P'algong seven species under four genera were collected during investigation periods (Table 1).

Seasonal trends and female reproductive conditions of *Carabus sternbergi* on Mt. Sobaek and Mt. P'algong are shown in Fig. 1 and Fig. 2. On Mt. Sobaek, this species was trapped from May and it reached its peak of activity late May to early July, and on Mt. P'algong it occurred from April at lower sites, and reached its seasonal peak in June to August. The reproductive females oc-

Table 2. Breeding patterns of the subtribe Carabina by female reproductive conditions on Mt. Sobaek and Mt. P'algong, Korea.

Species	Breeding type	Stage of hibernation
C. sternbergi *Li. venustus* *E. fraterculus* *D. leechi*	Spring breeder	Adult
Le. koreanus *Le. semiopacus* *Le. seishinensis* *D. jankowskii* *D. smaragdinus*	Autumn breeder	Larva and adult

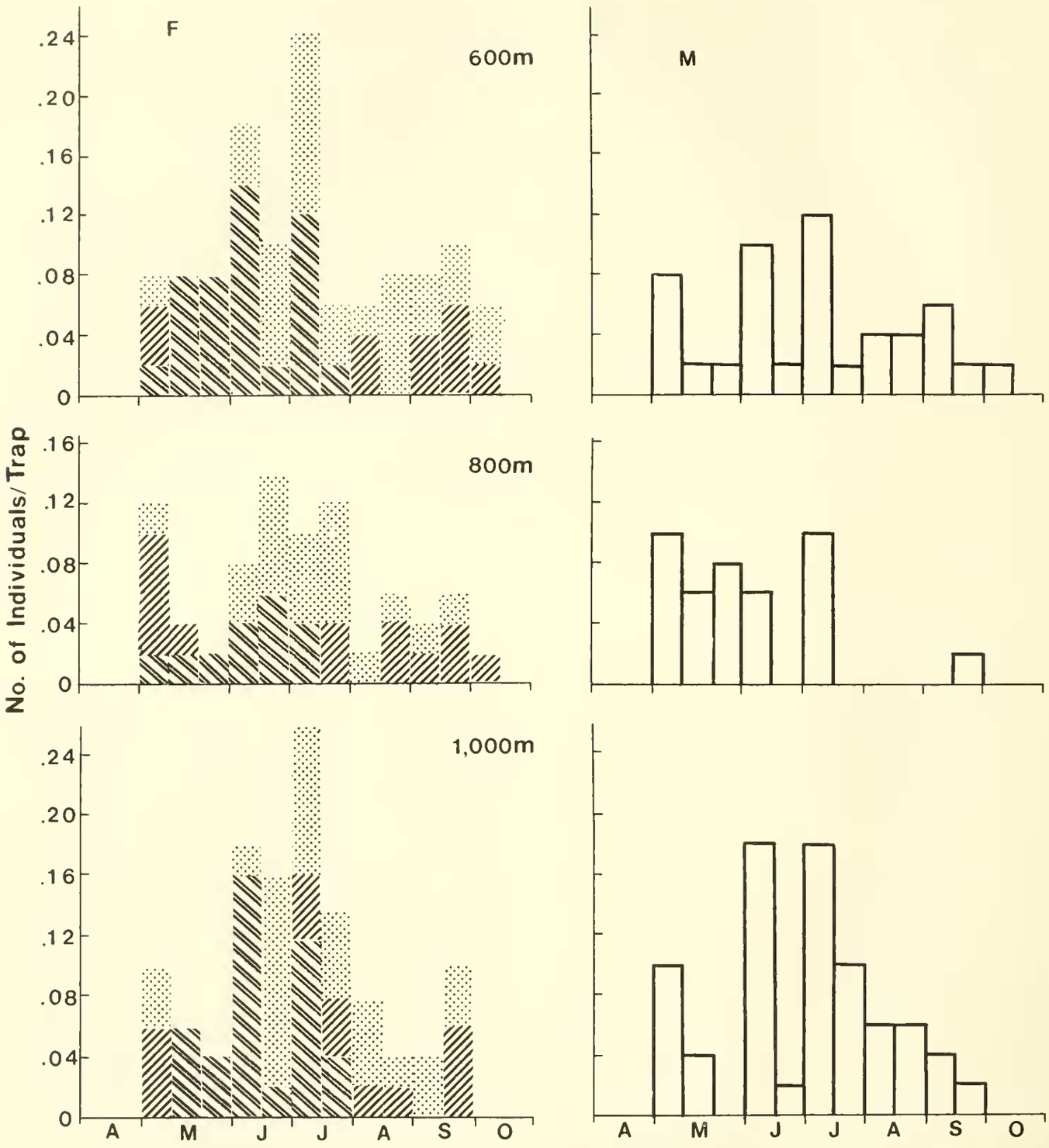


Fig. 1. The seasonal activity patterns of *Carabus sternbergi* on Mt. Sobaek (F, female; M, male; □, post reproductive adults; ▨, new adults; □, reproductive adults).

curred from spring to midsummer. The length of the reproductive period was three to three and a half months. Beginning in June, the increasing number of post reproductive females seemed to be a result of ovulation in May and the emergence of those in early spring was thought to be overwintered spent females of the last year(s). Therefore, it suggests that the life span of this species is two years or more. New adults which occurred from early spring may have been overwintered adults newly emerged during the last year. Those occurring in midsummer seemed to be mostly newly emerged adults during the year. Therefore, this species is obviously a spring breeder.

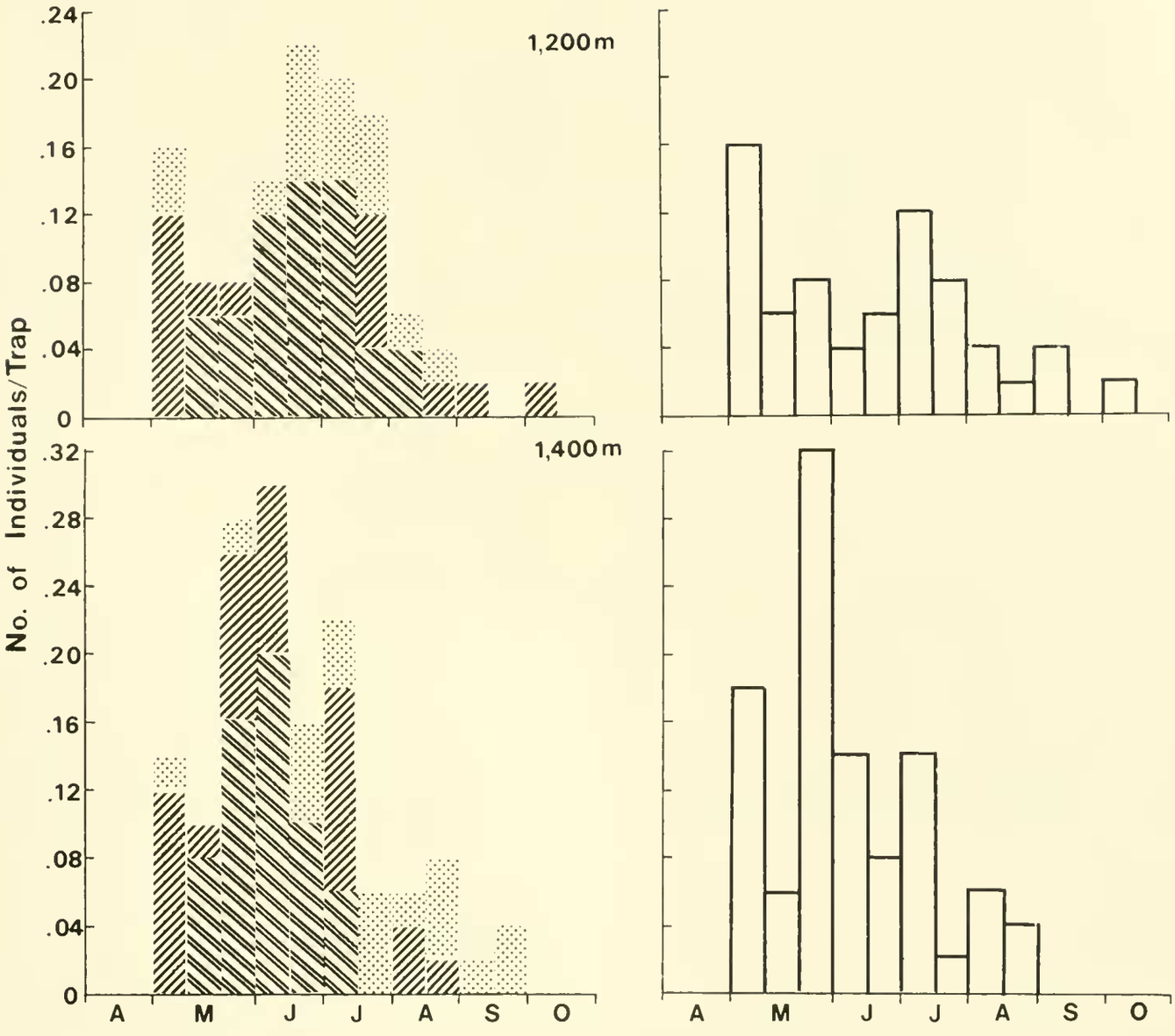
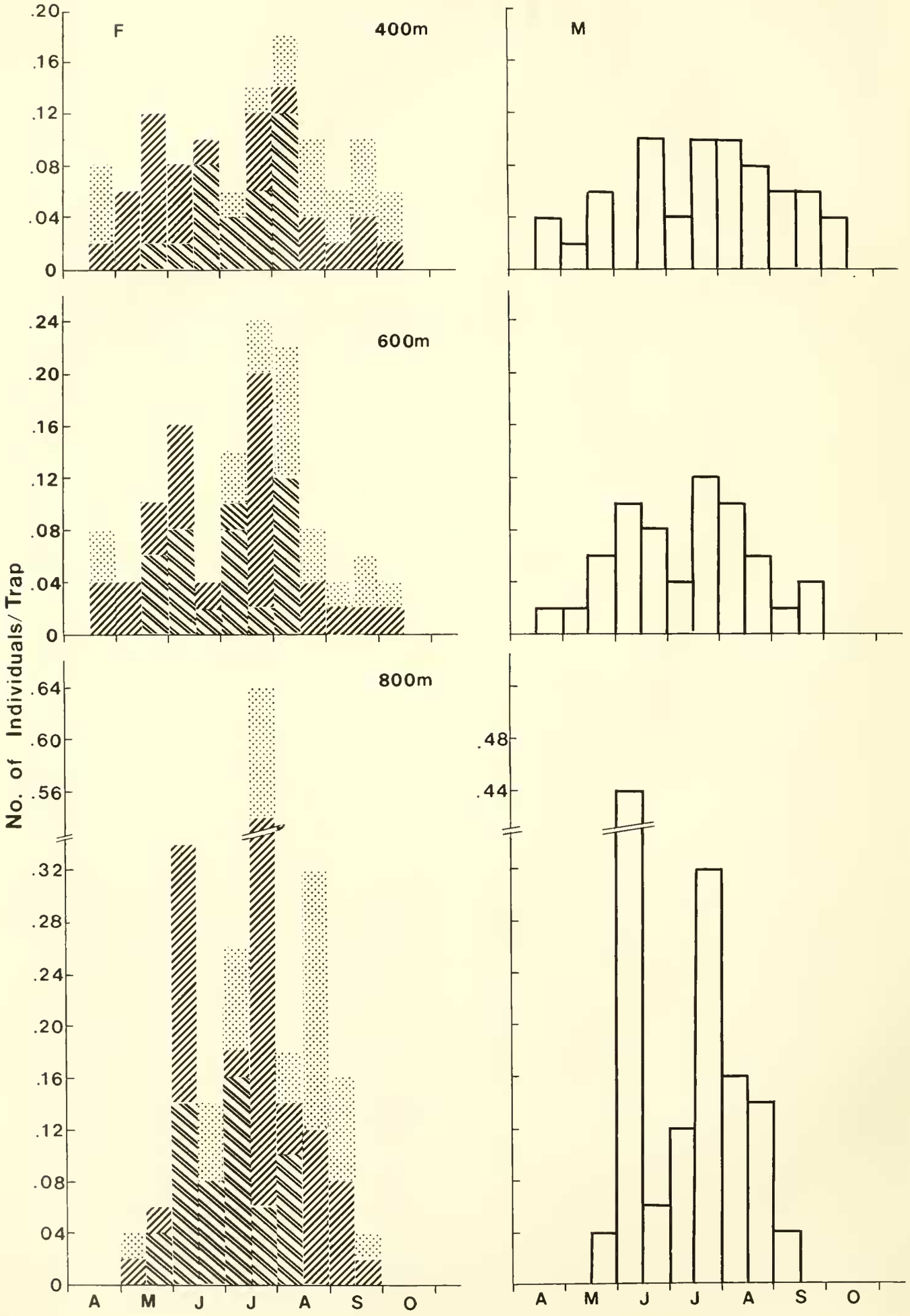


Fig. 1. Continued.

Leptocarabus semiopacus on Mt. Sobaek (Fig. 3) was collected from June or July and the time of occurrence at higher sites (above 1000 m) was slightly later than at lower sites. But on Mt. P'algong (Fig. 4), no difference was found along altitude in seasonal emergence as seen in July collections. They reached their seasonal peak during August in the two localities. On Mt. Sobaek, the reproductive females occurred from July to October, but reproduction began earlier at the higher altitudes (above 1000 m) which started in July while in the lower sites it started in August. The end of the reproductive season was from September to early October, but was also slightly earlier at the higher habitats. The length of the reproductive period indicated by the above results was about two to three months. On Mt. P'algong, that period was from August to September, but no distinct altitudinal differences were observed. In the two localities, during September and October no new adults were collected. This suggests that the hatched larvae do not develop to adults during the first year, hence, they hibernate as larvae. The collection of the spent females in June suggests that the life span of this species is also two years or more. From the above results, *L. semiopacus* is evidently an autumn breeder.

On Mt. Sobaek, *Leptocarabus seishinen-*


F
400m
M
600m
800m
No. of Individuals/Trap
.20
.16
.12
.08
.04
0
.24
.20
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.12
.08
.04
0
.64
.60
.56
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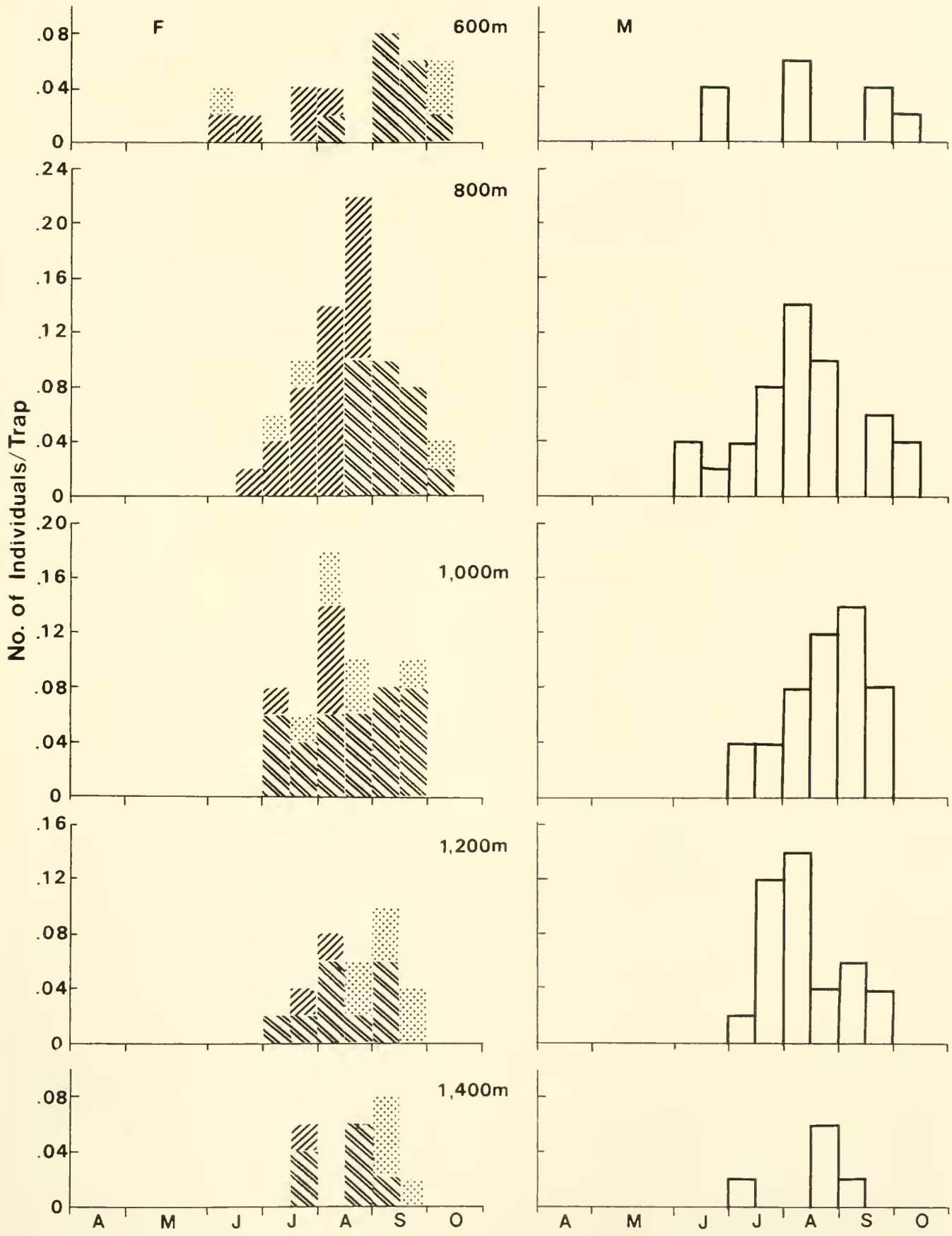

Fig. 3. The seasonal activity patterns of *Leptocarabus semiopacus* on Mt. Sobaek. For further explanations, see Fig. 1.

← Fig. 2. The seasonal activity patterns of *C. sternbergi* on Mt. P'algong. For further explanations, see Fig. 1.

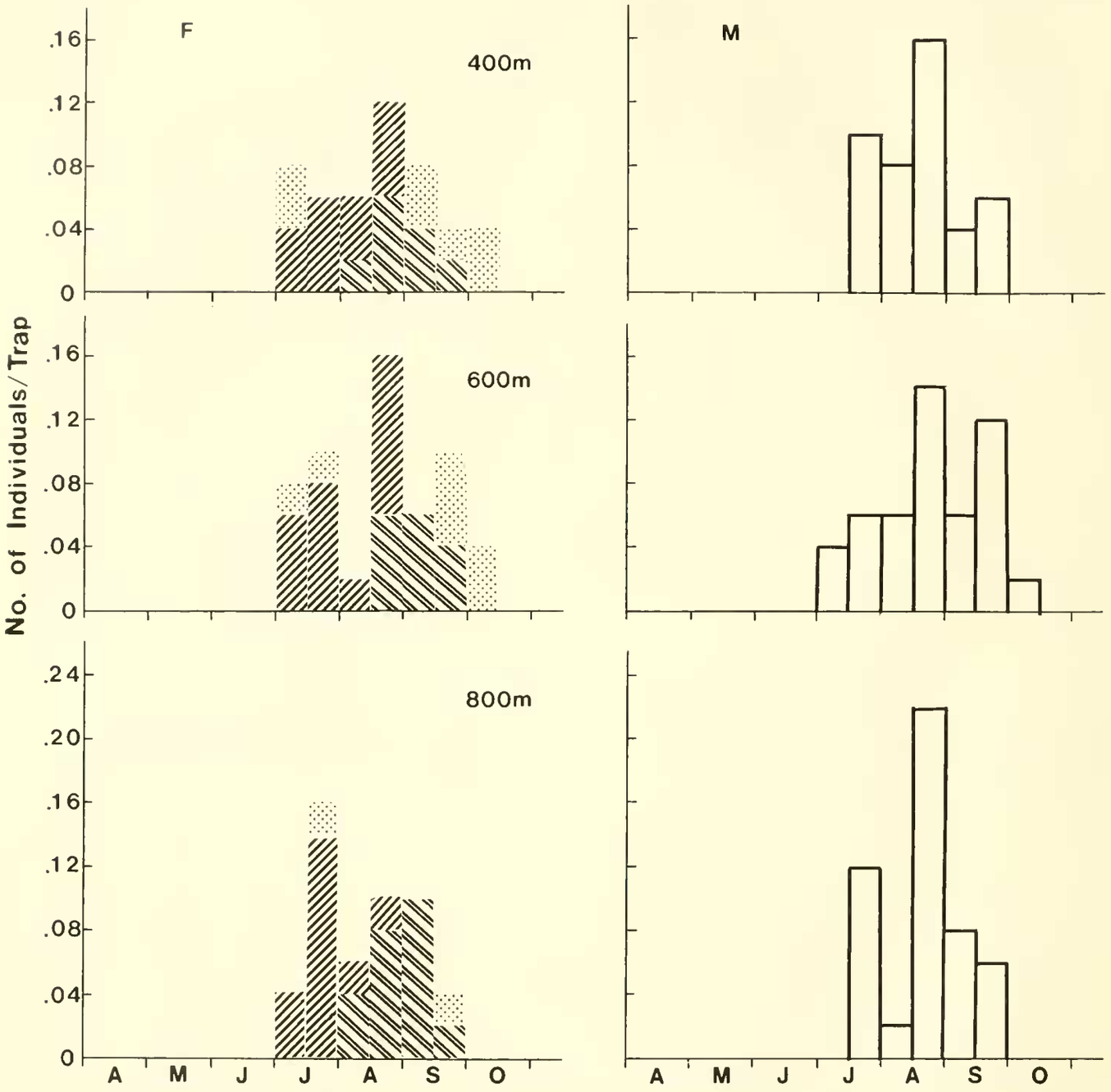

Fig. 4. The seasonal activity patterns of *L. semiopacus* on Mt. P'algong. For further explanations, see Fig. 1.

sis seishinensis was collected from June to early in October at the lower sites and from July to September at the higher sites (Fig. 5). Its reproductive females occurred in August at lower habitats and in July at the higher habitats. This continued to early in September at all habitats. At the higher sites, its reproductive period was longer than at the lower sites. And on Mt. P'algong (Fig. 6), this species was collected from June at 400 m and 600 m. It was collected during July at 800 m. Its reproductive females occurred from July to September. They reached their seasonal peak in midsummer in the two localities. Seasonal occurrences of the new and spent females of this species were similar to *L. semiopacus,* the autumn breeder. So from the results stated above, *L. seishinensis seishinensis* is an autumn breeder like the preceding species.

Damaster jankowskii jankowskii on Mt. Sobaek was trapped from early June to October at 600 m and in September at the other altitudes (Fig. 7). Its reproductive fe-

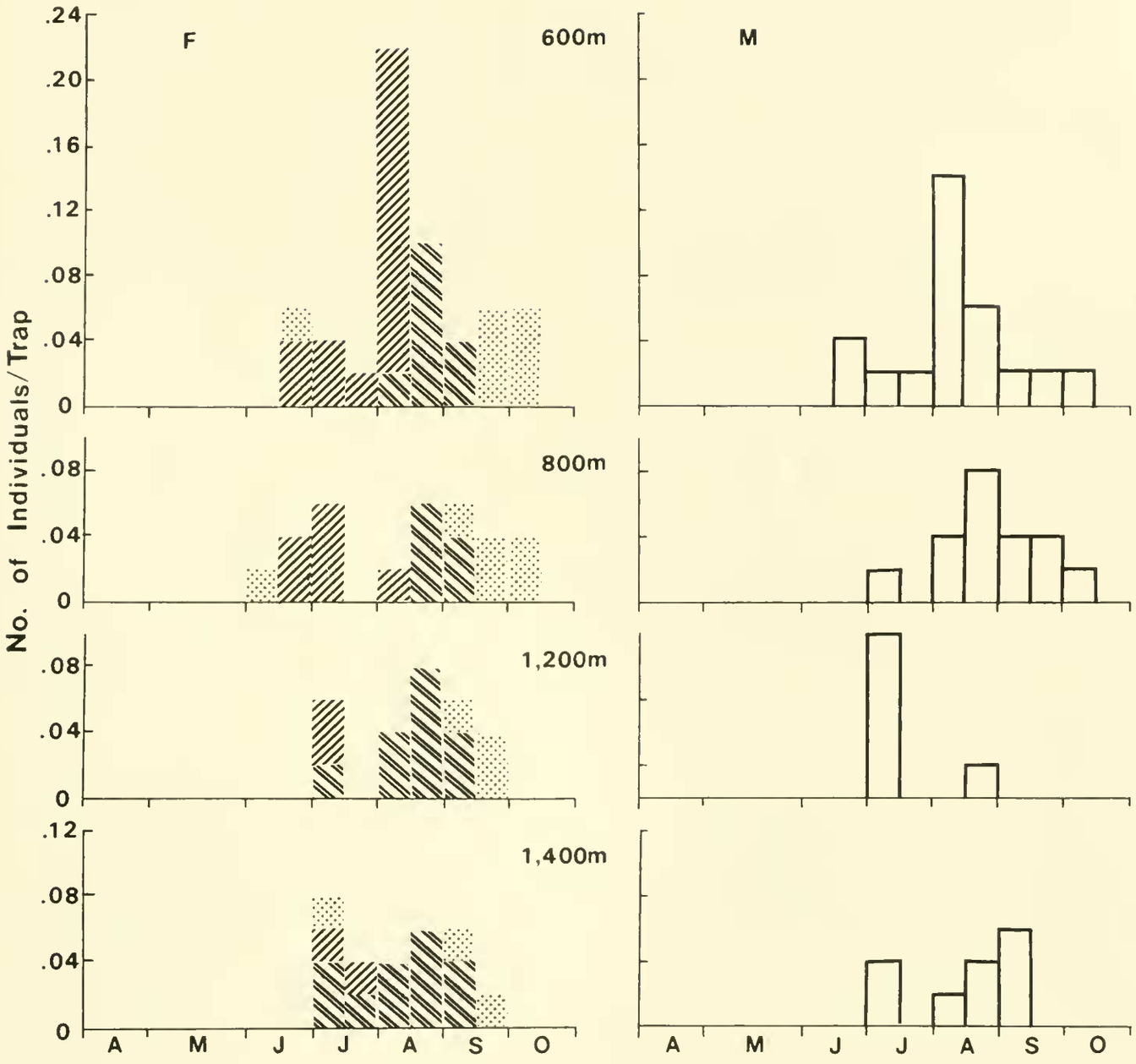

Fig. 5. The seasonal activity patterns of *Leptocarabus seishinensis seishinensis* on Mt. Sobaek. For further explanations, see Fig. 1.

males occurred from early July at lower sites and from late June at higher sites. On Mt. P'algong this species was collected from early June to September or early October and its reproductive females occurred from late June or early July (Fig. 8). In the two localities, this species reached its peak of activity in midsummer. Seasonalities of the new and spent females were very similar to the preceding autumn breeding types. Therefore this species is evidently an autumn breeder.

Eurycarabus fraterculus assimilis on Mt. Sobaek was collected in small numbers compared to the above species except at the highest site, 1400 m (Fig. 9). It appeared from May to September or October. At the highest site, it reached its peak of seasonal activity in spring. The reproductive females occurred from spring to midsummer. This species on Mt. P'algong was trapped in very small numbers. It is exhibited with the results from all sites in Fig. 9. The tendency of seasonality in this species was similar to that of *C. sternbergi,* the spring breeder. Therefore, it was concluded that this species is also a spring breeder.

Leptocarabus koreanus, Damaster leechi

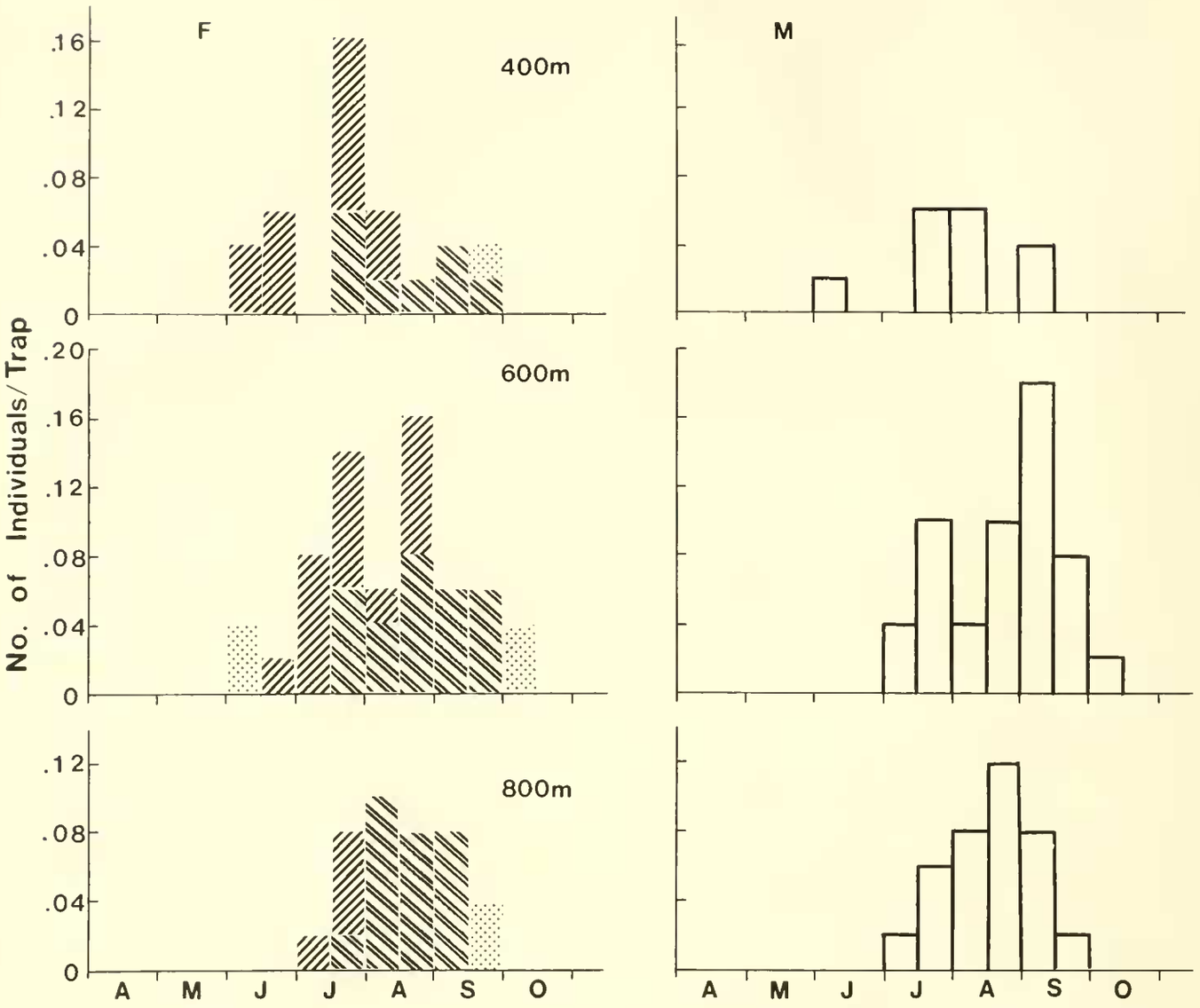

Fig. 6. The seasonal activity patterns of *L. seishinensis seishinensis* on Mt. P'algong. For further explanations, see Fig. 1.

and *Lipaster venustus taebeagsanus* rarely occurred on Mt. Sobaek (Fig. 10) only three females of *L. koreanus coreanicus* were trapped on Mt. P'algong during the entire sampling period. But judging from the appearance of the reproductive adults, *L. koreanus* is an autumn breeder and the other two species appear to be spring breeders. Although *Damaster smaragdinus branickii* on Mt. P'algong was also trapped in small numbers (Fig. 11) and only one female *D. smaragdinus fulminifer* on Mt. Sobaek was collected during the sampling period; this species appears to be an autumn breeder.

The results mentioned above are summarized in Table 2. Of total nine species from Mt. Sobaek and Mt. P'algong, four species, *C. sternbergi, L. venustus, E. fraterculus* and *D. leechi* were spring breeders hibernating as only adults, and five species, *L. koreanus, L. semiopacus, L. seishinensis, D. jankowskii* and *D. smaragdinus* were autumn breeders hibernating as larvae and older adults.

Discussion

The life history patterns of carabids are affected by geographical variations. Some differences of seasonalities were shown on Mt. Sobaek. It had more investigative sites and also a higher altitude than Mt. P'algong. Reproductive females of *Carabus sternber-*

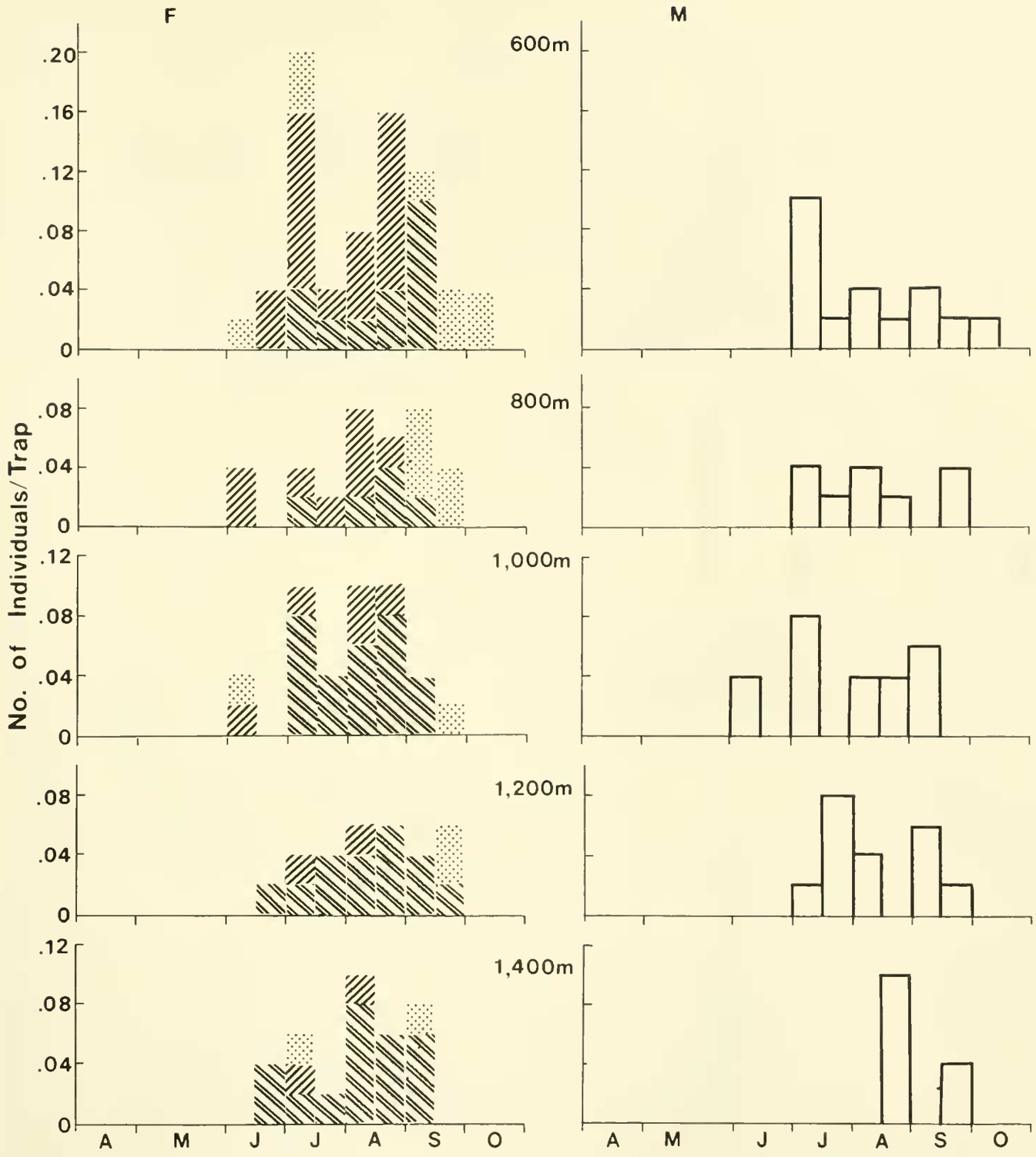

Fig. 7. The seasonal activity patterns of *Damaster jankowskii jankowskii* on Mt. Sobaek. For further explanations, see Fig. 1.

gi, the spring breeder, occurred slightly later at the higher altitudes (above 1000 m). Non-reproductive adults of *Leptocarabus semiopacus*, *L. seishinensis* and *Damaster jankowskii*, the autumn breeders, emerged earlier and reproductive forms occurred later at the lower sites. Through the study of the autumn breeder *Leptocarabus kumagaii*, Sota (1986a) explained this phenomenon as follows: The delay of new adult emergence at the higher altitudes is probably due to extended larval and pupal period under low temperatures at the higher altitudes. However, the absence of a hot sum-

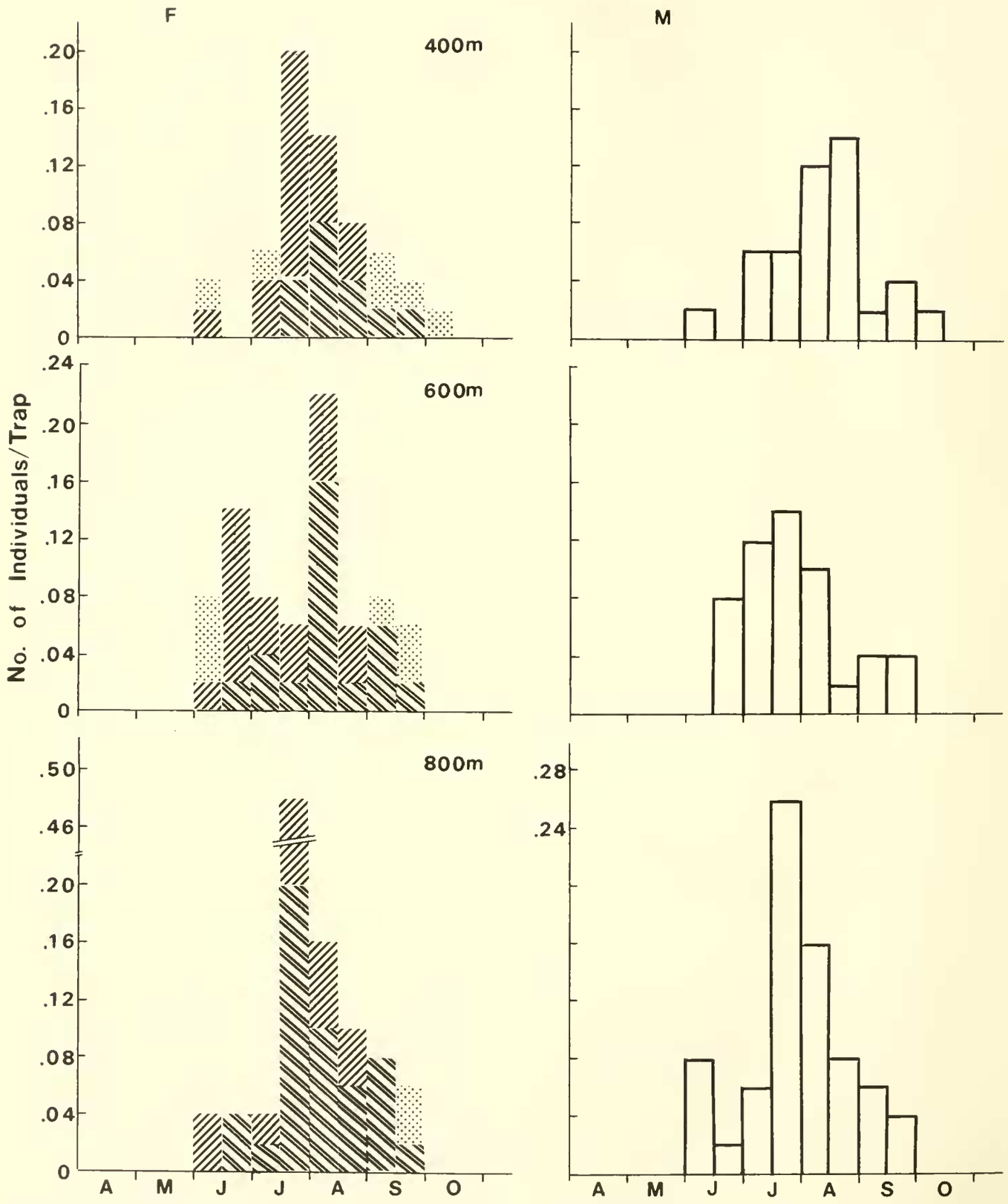

Fig. 8. The seasonal activity patterns of *D. jankowskii jankowskii* on Mt. P'algong. For further explanations, see Fig. 1.

mer at the higher altitudes seems to enable the beetles to start reproduction earlier. Using this point of view, we can conclude that the seasonal patterns of the above mentioned autumn breeders were similar to his results, and the delayed occurrence of reproductive adults of *C. sternbergi* at the higher sites can be explained by the climatic conditions. That is, at the higher altitudes under lower temperature, the vitellogenesis

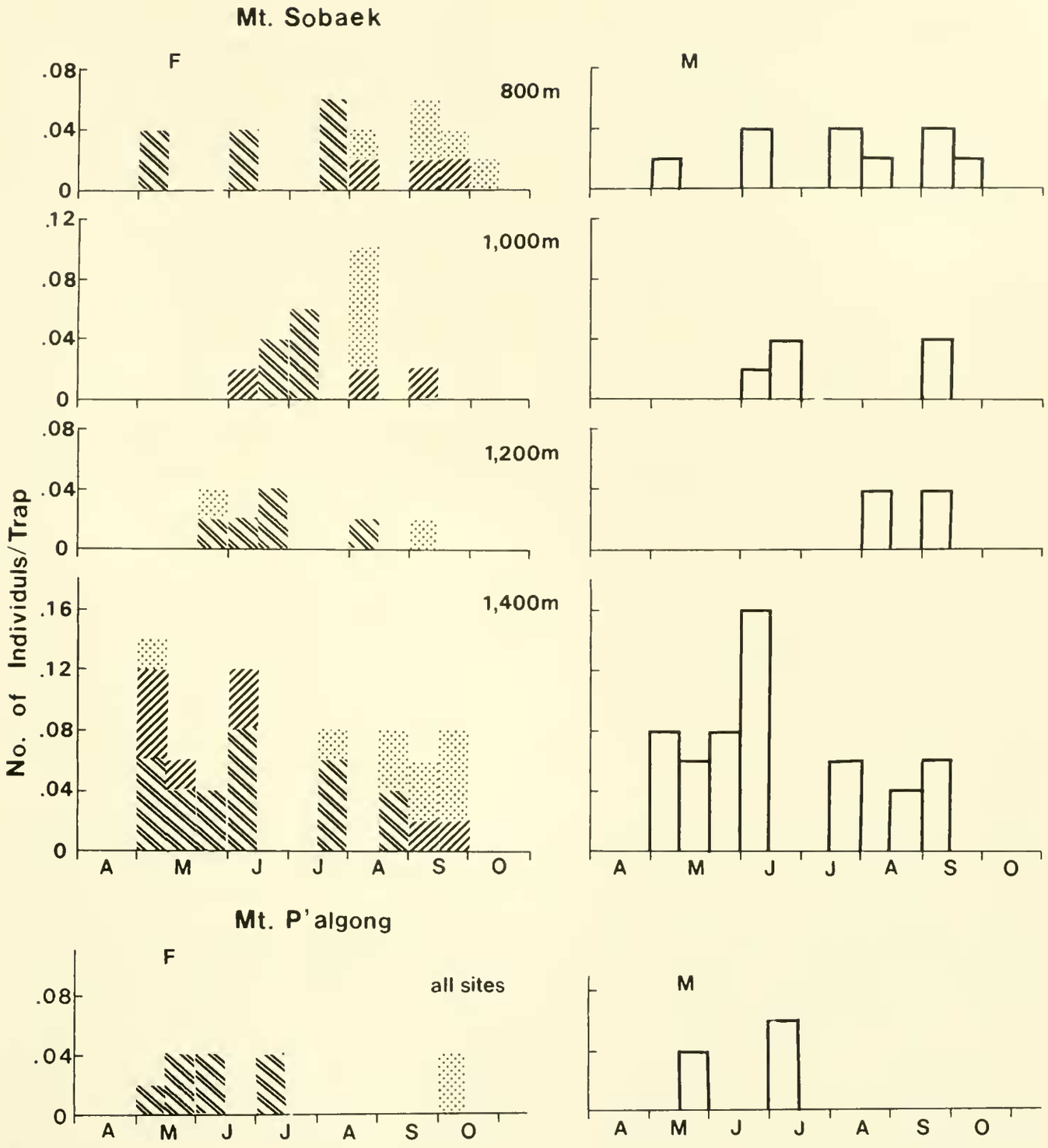

Fig. 9. The seasonal activity patterns of *Eurycarabus fraterculus assimilis* on Mt. Sobaek and Mt. P'algong. For further explanations, see Fig. 1.

of females will be delayed by the climatic condition. It is likely that other climatic factors such as the photoperiod and their surrounding environments also affect the insect life cycle patterns. There are many background interpretations (e.g. Brandmayr and Brandmayr 1986, Butterfield 1986, Danilevsky et al. 1970, Hemmer et al. 1986, Paarmann 1976, 1977, 1979, Refseth 1984, 1986, 1988, Sota 1986b, 1987, Tauber and Tauber 1973, 1976, Tauber et al. 1986, Thiele 1971, 1975, 1977, 1979a, b, Zaslavsky 1988). Hence a high degree of adaptations in response to these factors will be necessary if a species is to become widely distributed.

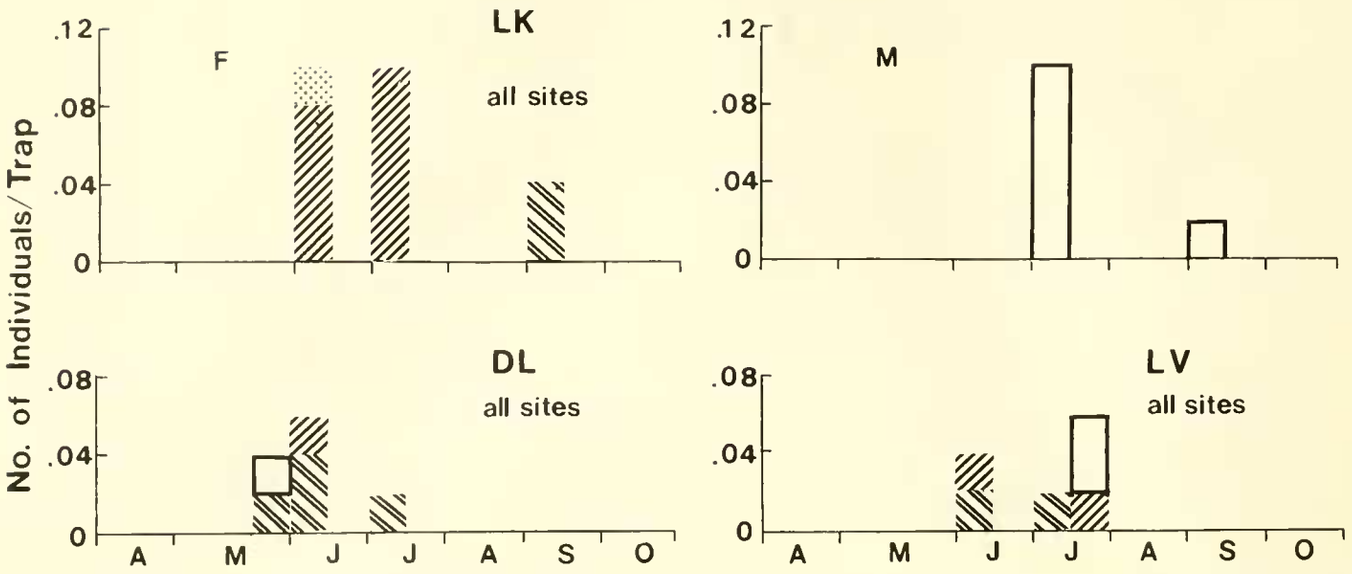

Fig. 10. The seasonal activity patterns of *Leptocarabus koreanus* (LK), *Damaster leechi* (DL) and *Lipaster venustus taebeagsanus* (LV) on Mt. Sobaek. For further explanations, see Fig. 1.

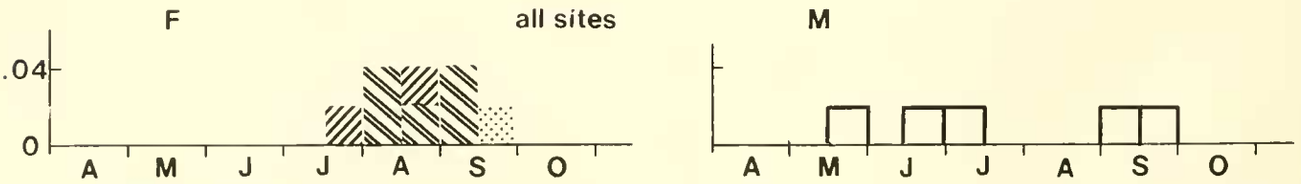

Fig. 11. The seasonal activity patterns of *Damaster smaragdinus branickii* on Mt. P'algong. For further explanations, see Fig. 1.

When reviewing the evolutionary considerations of the life cycles of the spring and autumn types, Paarmann (1979) stated the spring breeders seem to be the more advanced type because of their more complicated control of the gonad dormancy in females. Erwin (1979) suggested that evolution of Carabidae probably proceeded from wet (especially riparian) habitats to mesic ones like forests. According to his suggestion, Bousquet (1986) proposed it is more likely that autumn breeding is the derived condition while spring breeding is the ancestral condition because of their differences of habitats from his results that mainly spring breeders inhabited wet condition and autumn breeders inhabited forests. But in this study, differences of habitat conditions were not a factor. All of the investigated sites were forests and their composition percentages of both breeding types were also similar. To clarify the evolution of these carabids and their phylogenetic relationships, more detailed investigations are therefore required.

Den Boer (1980) reviewed that taxonomically closely related (carabid) insects, i.e. species in the same genus, can indeed be considered to be also ecologically closely related. From his results, he noted in many genera most species do show the same type of annual reproduction rhythm, and as a whole this phenomenon is highly significant. When compared with the results of the present study and Sota (1985), genera *Carabus* as spring breeder and *Leptocarabus* as autumn breeder had the same life cycle types. But in the case of genus *Damaster*, it appeared to be dissimilar, that is, in this paper *D.* (*Coptolabrus*) *jankowskii* and *D.* (*C.*) *smaragdinus* were autumn breeders while *D.* (*Acoptolabrus*) *leechi* was a spring breeder. In his result, *D. blaptoides* was a spring breeder. This species belongs to subgenus

Damaster. From these results, it is concluded that in the genus *Damaster*, their breeding types are separated by subgeneric levels. The differences among subgenera in this genus need further research in viewpoint of phylogeny (see Ishikawa 1986).

Acknowledgments

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Literature Cited

Bousquet, Y. 1986. Observations on the life cycle of some species of *Pterostichus* (Coleoptera, Carabidae) occurring in northeastern North America. Le Naturaliste Canadien (Revue d'écologie et de Systématique) 113: 295–307.

Brandmayr, P. and T. Z. Brandmayr. 1986. Phenology of ground beetles and its ecological significance in some of the main habitat types of southern Europe, pp. 195–220. *In* Den Boer, P. J. et al., eds., Carabid Beetles; Their Adaptations and Dynamics. Gustav Fischer, Stuttgart, New York.

Butterfield, J. E. L. 1986. Changes in life-cycle strategies of *Carabus problematicus* over a range of altitudes in northern England. Ecological Entomology 11: 17–26.

Danilevsky, A. S., N. I. Goryshin, and V. P. Tyshchenko. 1970. Biological rhythm in terrestrial arthropods. Annual Review of Entomology 15: 201–244.

Den Boer, P. J. 1980. Exclusion or coexistence and the taxonomic or ecological relationship between species. Netherlands Journal of Zoology 30: 278–306.

Erwin, T. L. 1979. Thoughts on the evolutionary history of ground beetles: Hypotheses generated from comparative faunal analyses of lowland forest sites in temperate and tropical regions, pp. 539–592. *In* Erwin, T. L. et al., eds., Carabid Beetles; Their Evolution, Natural History and Classification. Junk, The Hague.

Hemmer, J., M. Klenner, H. Niesing, and F. Weber. 1986. Life history phenomenon in subpopulation of *Carabus auronitens* F. from the Westphalian lowland, pp. 439–464. *In* Den Boer, P. J. et al., eds., Carabid Beetles; Their Adaptations and Dynamics. Gustav Fischer, Stuttgart, New York.

Ishikawa, R. 1986. Phylogeny and subgeneric classification of the genus *Damaster* Kollar (Coleoptera, Carabidae), pp. 115–130. *In* Entomological Papers presented to Yoshihiko Kurosawa on the occasion of his retirement, Tokyo.

Ishikawa, R. and J. L. Kim. 1983. New or little known Carabina of Korea. Nature and Life 13(2): 69–82.

Kwon, Y. J. and S. M. Lee. 1984. Classifications of the subfamily Carabinae from Korea (Coleoptera, Carabidae). Insecta Koreana, Ser. 4. 363 pp. (including 107 pls.)

Lindroth, C. H. 1949. Die fennoskadischen Carabidae. Eine tiergeographische Studie. III. Algemeiner Teil. Gôteborgs Kungl. Vetenskaps-och Vitterhets-Samhälles Handlingar, Ser. B 4(3): 1–911.

Paarman, W. 1976. Jahreszeitliche Aktivität und Fortpflanzungs rhythmik von Laufkäfern (Col., Carabidae) in Kivugebiet (Ost-Zaire, Zentralafrika). Zoologische Jahrbucher Systematik Ökologie und Geographie 103: 311–354.

———. 1977. Propagation rhythm of subtropical and tropical Carabidae (Coleoptera) and its control by exogenous factors. Advances in Invertebrate Reproduction 1: 49–60.

———. 1979. Ideas about the evolution of the various annual reproduction rhythms in carabid beetles of the different climatic zones. Miscellaneous Papers Landbouwhogeschool Wageningen 18: 119–132.

Refseth, D. 1984. The life cycles and growth of *Carabus glabratus* and *C. violaceus* in Budalen, central Norway. Ecological Entomology 9: 449–455.

———. 1986. Phenological adaptations in *Patrobus atrorufus* and *P. assimilis* (Col., Carabidae). Fauna norvegica Ser. B 33: 57–63.

———. 1988. Annual patterns of activity, reproduction and development in some Norwegian Carabidae (Col.). Fauna norvegica Ser. B 35: 21–30.

Sota, T. 1985. Life history patterns of carabid beetles belonging to the subtribe Carabina (Col., Carabidae) in the Kinki District, western Japan. Kontyu, Tokyo 53(2): 370–378.

———. 1986a. Carabid populations along altitudinal gradient: Life history variation of *Leptocarabus kumagaii* (Coleoptera, Carabidae), pp. 429–438. *In* Den Boer, P. J. et al., eds., Carabid Beetles, their Adaptations and Dynamics. Gustav Fischer, Stuttgart, New York.

———. 1986b. Effects of temperature and photoperiod on the larval development gonad maturation of carabid beetle, *Carabus yaconinus* (Coleoptera, Carabidae). Applied Entomology and Zoology 21(1): 89–94.

———. 1987. Effects of temperature and photoperiod on the larval hibernation and adult aestivation of *Leptocarabus kumagaii* (Coleoptera, Carabidae). Applied Entomology and Zoology 22(4): 617–623.

Tauber, M. J. and C. A. Tauber. 1973. Insect phenology: Criteria for analyzing dormancy and for

forecasting postdiapause development and reproduction in the field. Search (Agriculture) Cornell University Agricultural Experiment Station, Ithaca, New York 3: 1–16.

———. 1976. Insect seasonality; diapause maintenance, termination, and post diapause development. Annual Review of Entomology 21: 81–107.

Tauber, M. J., C. A. Tauber, and S. Masaki. 1986. Seasonal adaptations of insects. Oxford Univ. Press, New York, Oxford. 411 pp.

Thiele, H. U. 1971. Die Steuerung der Jahresrhythmik von Carabiden durch exogene und endogen Faktoren. Zoologische Jahrbucher Systematik Ökologie und Geographie 98: 341–371.

———. 1975. Interactions between photoperiodism and temperature with respect to the control of dormancy in the adult stage of *Pterostichus oblongopunctatus* F. (Coleoptera, Carabidae). Oecologia (Berl.) 19: 39–47.

———. 1977. Carabid Beetles in Their Environments. Springer-Verlag, Berlin, Heidelberg, New York. 369 pp.

———. 1979a. Intraspecific differences in photoperiodism and measurement of day length in *Pterostichus nigrita* Paykull (Coleoptera, Carabidae). Miscellaneous Papers Landbouwhogeschool Wageningen 18: 53–62.

———. 1979b. Relationships between annual and daily rhythms, climatic demands, and habitat selection in carabid beetles, pp. 449–470. *In* Erwin, T. L. et al., eds., Carabid Beetles; Their Evolution, Natural History, and Classification. Junk, The Hague.

Zaslavsky, V. A. 1988. Insect Development. Photoperiodic and Temperature Control. Springer-Verlag, Berlin, Heidelberg, New York, London, Paris, Tokyo (English translation). 187 pp.